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Tolerance of young trees to foliar acting herbicides

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Summary

An experiment tested the tolerance of 20 actively growing broadleaved and coniferous tree species to various foliar acting herbicides. Treatments were applied at two dates (early and mid-season) and two rates. Survival, height and stem diameter increments were recorded at the end of the first and second growing seasons. Conifers were found to be generally more tolerant than broadleaved species. Cycloxydim was tolerated by most species and may be an effective option for in season control of established grasses. Most of the conifer species tested exhibited some tolerance to amidosulfuron and tribenuron methyl, but broadleaves were more susceptible to damage. Pyridate and cyanazine reduced the growth of most broadleaved species, but conifers showed more resistance. More work is required to confirm the effects of amidosulfuron, tribenuron methyl and pyridate on actively growing and dormant tree species before any firm conclusions can be drawn on their safety as potential alternatives to the use of triazines for woodland establishment.

Key words: Herbicides, trees, cyanazine, pyridate, amidosulfuron, tribenuron methyl, cycloxydim

Introduction

Triazine herbicides have been widely and successfully used in forestry for many years (Willoughby & Dewar, 1995), because they are relatively cheap, selective, and give effective control of most annual and perennial weed species. However, the use of triazine herbicides is being restricted in many countries because of concerns about the contamination of ground water. There is therefore a pressing need to develop alternative weed control treatments. Although some alternatives to the use of herbicides exist and should be utilised as a first resort where possible (Willoughby *et al.*, 2004), the immediate adoption of a wholly chemical free approach is unlikely to be practical in many situations given the cost implications, particularly with afforestation and restocking on more fertile soils.

Carefully directed sprays of broad-spectrum herbicides offer one option for control of established vegetation around trees, but such an approach is not always practical. Overall spraying with residual herbicides or graminicides in bands or spots along the tree lines requires less precision and can be used to control many weed species (Williamson *et al.*, 1992; Willoughby & Clay, 1996). However, where herbaceous weeds establish, in forestry situations only clopyralid (Dixon *et al.*, 2005; Lawrie & Clay, 1994*a*) or asulox (Willoughby & Dewar, 1995) have been shown to be generally safe to use as sprays over actively growing trees, and these herbicides only control a limited range of weed species.

Foliar-acting sulfonyl urea herbicides have become widely and successfully used for broadleaved weed control in arable crops in the UK, where they are often perceived to be environmentally benign because of the very low quantities of active ingredients used, limited soil persistence and their low mammalian toxicity (Tomlin, 1997). Limited evidence suggests dormant conifers and broadleaves may tolerate applications of tribenuron methyl or amidosulfuron (Fraser *et al.*, 2001; Dixon *et al.*, 2006), and some actively growing conifers can also exhibit tolerance (Lawrie & Clay, 1994*a,b*; Dixon *et al.*, 2006). However actively growing broadleaves are often severely damaged (Clay *et al.*, 1992; Clay & Dixon, 1993; Britt *et al.*, 2000; Fraser *et al.*, 2001; Dixon *et al.*, 2006)

Pyridate is a foliar-acting herbicide effective on a wide range of broadleaved weed species when applied to small actively growing seedlings (Dixon & Clay, 2004). Overall spraying of some broadleaved tree species in active growth has been reported as giving only slight, short-term damage (Dixon & Clay, 1996; Dixon *et al.*, 2006).

Given the imminent withdrawal of triazines from the market, it seems opportune to review the data from previously unpublished tree tolerance experiments carried out in recent years, to see if any potential replacements can be identified. Hence in this paper a previously unreported experiment is detailed, whose objective was to test the tolerance of a range of tree species to pyridate, amidosulfuron and tribenuron methyl. Cycloxydim was also included in order to gain experience of the safety of this active on a wider range of species, and the triazine, cyanazine, was used for comparison.

Materials and Methods

The experiment was carried out at Headley Nursery (UK Grid Reference: SU 808 379; 51º 08′ N, 1º 51′ W). The site is 90 m above sea level and is level with average annual rainfall of 805 mm. The soil is a Humic-ferric podzol, Shirrell Heath Series 1 (Mackney *et al.*, 1983). Twenty species (shown in Table 2) were planted in March 1996 at 5 cm spacing with each species planted in a separate row and 25 cm between species rows. Each plot contained 10 trees of each species with a minimum 1 m buffer zone between plots. Trees were 1–2 year-old nursery transplants except for lodgepole pine which was undercut, and poplar and willow which were cuttings. Six herbicide treatments (Table 1) were applied at two rates (classed as ‘normal’ and 2 × ‘normal’ application rates) and two dates (6 June, as soon as all species were fully flushed, and mid-season on 17 July) giving a total of 24 treatments. Each treatment was applied to one of 24 plots and there were two replicate blocks (48 plots in total). Treatments were applied using a Cooper Peglar CP15 knapsack sprayer with a green fan-jet nozzle at one bar (1200 mL min^{-1}). The site was fenced against deer and rabbits. Tree height (cm) and stem diameter (mm) at 10 cm above ground level of every tree was recorded immediately after planting and at the end of the first and second growing season. Health scores were assessed four weeks after herbicide application using a scale of 1–5 (1=healthy, 5=dead) in the first growing season only.

Analysis of variance was carried out (Genstat, 2003) using plot mean height and stem diameter increments (HtI and SDI) for each species individually. Analysis of survival was carried out using a binomial generalised linear model with a logit-link function. In cases where 100% survival resulted in arbitrary large parameter estimates the usual t-test comparison between parameters was supplemented by Fisher’s exact test. In all analyses the four control plots were combined. LSDs are at the 5% level.

Results

Year one data are presented for the June application only. July data and year two data are only discussed where the results differed from the June or year one data. Health scores are not shown.

Survival

Table 2 shows height and stem diameter increment at the end of the first growing season resulting from the June treatment. Poplar and western red cedar were the only species for which any of the herbicides caused significant reduction in survival compared with the control treatment. For poplar, the June application of 2× cyanazine reduced survival. For western red cedar the June application of 2× amidosulfuron and July applications (data not shown) of 1× amidosulfuron, 2× pyridate and 1× and 2× tribenuron methyl caused significantly lower survival than in the control treatment.

However, substantial non-significant effects were also seen; cyanazine appeared to reduce the survival of Norway maple and poplar; pyridate reduced the survival of beech and Norway maple and tribenuron methyl reduced the survival of beech and Scots pine. These non-significant reductions in survival compared to the control were between 6.25–33.75%. Although survival of Japanese larch was poor and variable this was unrelated to the herbicide treatments.

Height and stem diameter increment

Amidosulfuron

Amidosulfuron had a severe effect on the growth of alder and poplar (Stem diameter was not measured for poplar), regardless of rate or application date (Table 2). Compared to the control, HtI of Norway maple (and Corsican pine at the 2× rate only) were reduced by the June application but other species were unaffected. July application of amidosulfuron at the 1× rate caused a reduction of HtI in Sitka spruce and in SDI of sycamore. By end of the second growing season, only the HtI of alder remained significantly suppressed due to the June and July 2× applications, while growth of the other species had apparently recovered. Amidosulfuron did not severely affect health scores (data not shown) except for poplar and willow which had a mean health score of 3 for both 1× and 2× rates at both application dates.

Cyanazine

Cyanazine had a damaging effect on many species, with the June application causing reductions in HtI compared to the control in alder, birch, Norway maple, poplar, sycamore, willow and Sitka spruce (and cherry with the 2× rate only). SDI was also reduced for alder, ash, cherry and Norway maple. The effect persisted into the second growing season with alder, beech, birch, Japanese larch, sycamore and willow having reduced HtI and ash and Corsican pine being affected by the 2× rate only. Growth of Norway maple, poplar, Sitka spruce and cherry appeared to recover by the end of the second year.

The July applications tended to result in reduction of SDI rather than HtI. SDI increment was reduced by July applications for alder, ash, beech, cherry, Norway maple and sycamore (and birch for 2× rate only) while HtI was reduced for alder, birch, Norway maple, poplar and sycamore but only at the higher rate. The 1× rate had no effect on HtI of any species when applied in July. The July application had no long-lasting effects on HtI.

The 2× rate application of cyanazine resulted in mean health score of 3 for alder, ash, beech, birch, cherry, poplar, sweet chestnut and willow at one or both of the application dates; largely the species which had suppressed growth.

Cycloxydim

The June applications of cycloxydim were relatively safe, only suppressing HtI in Norway maple and sycamore (and Corsican pine at the 2× rate only). SDI was not reduced for any species. By the end of the second growing season, growth of Norway maple and sycamore recovered, but the June application of 1× cycloxydim had apparently caused a reduction in HtI of beech that was not evident in year 1. The July application caused no growth suppression in any species except for the SDI of sycamore at both 1× and 2× rates. There were no significant effects of the July applications in year two.

Cycloxydim had the least effect on tree health; the worst health score of 3 resulting from the higher rate application in June to Scots pine although growth of this species was not affected.

Pyridate

Pyridate applications had a damaging effect on many of the species. The June applications caused reductions in HtI compared to the control in alder, birch, Corsican pine, Norway maple, oak, poplar, sycamore, willow and Sitka spruce (and ash, beech and lodgepole pine at the 2× rate only). SDI was reduced for alder, ash, beech, birch, Norway maple, sycamore, Sitka spruce (and Norway spruce at the 2× rate only). By the end of the second growing season there was a significant effect of pyridate on HtI of alder, ash, beech, birch, Corsican pine, Japanese larch, lodgepole pine, Norway spruce, Sitka spruce, sycamore and willow.

The July applications were much less damaging to HtI (only sycamore and Norway maple were affected) and to SDI (only ash, Norway maple and sycamore were affected) and this did not persist into the second growing season.

Ash, beech, Japanese larch, Norway maple, sweet chestnut and Scots pine had mean health scores of 3, usually for higher rate applications, although not all of these species had reduced growth.

Tribenuron methyl

The June application of tribenuron methyl suppressed HtI of alder, Norway maple, poplar and sycamore at both 1× and 2× rates. SDI of alder and ash were also significantly reduced by these treatments. By the end of the second year, the effect of the June application on HtI of alder and sycamore remained significant and a reduction of HtI of ash was also recorded (not evident in year 1). The July applications also suppressed HtI of alder, Norway maple, poplar, sycamore and Sitka spruce, and SDI of alder, ash, cherry, Norway maple and sycamore, with HtI of alder remaining suppressed in year 2.

Mean health scores of poplar and willow were 3 for both 1× and 2× rates at both application dates. Cherry, Japanese larch, noble fir, Scots pine and western red cedar also had poor health scores, usually associated with the June application, however, other than poplar and cherry, these species did not have reduced growth.

Discussion

There was no statistically significant effect of the herbicide treatments on survival other than on poplar and western red cedar; the damaging effect of the herbicides was more often manifest in a reduction of HtI and/or SDI. The broadleaved species were generally more susceptible than the coniferous species, and the June application of the herbicides tended to result in worse damage and longer lasting damage than the July application. However, as there were several large but statistically non-significant reductions in survival, caution needs to be exercised when making any judgements on likely tree species tolerance to overall sprays of these herbicides.

Cycloxydim was the least damaging of the herbicides with few species being consistently affected at standard dose rates. Those species that were apparently damaged largely recovered by the end of the second growing season.

The two sulfonyl urea herbicides, amidosulfuron and tribenuron methyl, had very similar effects on many of the species. All actively growing conifer species in this study appeared to be largely tolerant to applications of these herbicides at the lower dose rates, echoing the results of Lawrie & Clay (1994 a, b) and Dixon *et al*. (2006). Many actively growing broadleaved species, such as alder, poplar, Norway maple (and for tribenuron methyl only, ash and sycamore) were severely damaged by these herbicides, as was also found by Clay *et al*. (1992), Clay & Dixon (1993), Britt *et al*. (2000), Fraser *et al*. (2001) and Dixon *et al*. (2006). However, birch, willow, oak, beech, cherry and sweet chestnut did not appear to be severely affected by the lower dose rates of sulfonyl urea herbicides used in this study. The two sulfonyl urea herbicides, amidosulfuron and tribenuron methyl, had very similar effects on many of the species. All actively growing conifer species in this study appeared to be largely tolerant to applications of

Table 1. *Herbicide details*

Herbicide	Manufacturer	Rate code	Application rate (kg a.i. ha^{-1})	Product	Equivalent product rate
Control	n/a	0	0	n/a	n/a
Cyanazine	Makhteshim-Agan (UK) Ltd	1	2	Fortrol (500 g L^{-1} cyanazine)	4 L ha^{-1}
		2	4		8 L ha^{-1}
Pyridate	Syngenta Crop Protection UK Ltd	1	0.9	Lentagran (45% w/w)	2 kg ha^{-1}
		2	1.8		4 kg ha^{-1}
Amidosulfuron	Bayer CropScience Ltd	1	0.03	Eagle (75% w/w)	40 g ha^{-1}
		2	0.06		80 g ha^{-1}
Tribenuron methyl	DuPont (UK) Ltd	1	0.015	Quantum (50% w/w)	30 g ha^{-1}
		2	0.03		60 g ha^{-1}
Cycloxydim	BASF plc	1	0.45	Laser (200 g L^{-1} cycloxydim)	2.25 L ha^{-1} (*0.8%)
		2	0.9		4.50 L ha^{-1} (*1.6%)

- Plus Actipron adjuvant oil (97% highly refined mineral oil; Joseph Batsons Ltd.) at 0.8% of final spray volume. Rate code 1 "normal" application rate; Rate code 2 "2× normal" application rate.

Table 2. *Survival, height increment (HtI) and stem diameter increment (SDI) at the end of the first growing season for the June application only*

Species		Alder *Alnus glutinosa* (L.) Gaertn.			Ash *Fraxinus excelsior* (L.)			Beech *Fagus sylvatica* (L.)			Birch *Betula pendula* (Roth.)		
Herbicide	Rate	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.
Control	0	61.4	4.84	99[a]	11.8	2.83	95[a]	17.4	2.39	96[a]	72.1	5.54	99[a]
Amidosulfuron	1	23.5	3.68	100[a]	12.8	3.50	90[a]	19.5	2.80	100[a]	62.8	6.25	100[a]
	2	16.7	3.03	100[a]	7.4	2.93	100[a]	18.1	2.88	95[a]	53.1	5.88	100[a]
Cyanazine	1	33.5	3.45	100[a]	9.1	1.50	90[a]	14.0	2.48	100[a]	42.9	4.15	100[a]
	2	39.4	4.10	100[a]	5.2	1.23	90[a]	11.8	1.45	100[a]	42.5	4.13	100[a]
Cycloxydim*	1	54.4	4.63	100[a]	6.3	2.40	100[a]	11.2	1.78	100[a]	69.5	6.93	100[a]
	2	51.1	5.25	100[a]	14.8	3.29	90[a]	14.3	1.98	100[a]	66.2	5.95	100[a]

Pyridate	1	30.0	3.25	100[a]	5.0	0.76	90[a]	12.0	1.34	90[a]	33.4	3.28	95[a]
	2	30.5	3.43	100[a]	3.2	0.95	100[a]	9.5	1.75	100[a]	43.5	4.43	100[a]
Tribenuron methyl	1	18.4	2.03	100[a]	5.7	1.85	100[a]	16.0	2.46	90[a]	64.7	6.43	100[a]
	2	22.1	3.15	100[a]	6.1	1.68	100[a]	15.2	2.33	100[a]	55.9	5.93	100[a]
P control *vs* herbicide (df 4,26)		<0.001	<0.001	-	0.120	<0.001	-	0.004	<0.001	-	0.007	<0.001	-
SED control *vs* treatment (df 26)		7.21	0.558	-	3.62	0.407	-	3.23	0.506	-	10.70	0.807	-
LSD control *vs* treatment (df 26)		14.82	1.148	-	7.44	0.837	-	6.64	1.040	-	21.90	1.660	-

Species		Cherry *Prunus avium* (L.)			Norway Maple *Acer platanoides* (L.)			Oak *Quercus robur* (L.)			Poplar *Populus* sp.		
Herbicide	Rate	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.
Control	0	44.8	4.49	100[a]	20.2	2.64	96[a]	15.8	1.90	99[a]	192.4	m	99[b]
Amidosulfuron	1	34.2	5.00	100[a]	8.4	2.78	95[a]	22.6	3.10	100[a]	120.0	m	100[b]
	2	26.3	4.85	100[a]	6.7	2.63	100[a]	19.3	2.65	100[a]	95.9	m	100[b]
Cyanazine	1	43.1	2.93	100[a]	4.0	1.58	95[a]	11.4	2.15	95[a]	147.2	m	95[b]
	2	24.7	3.70	100[a]	5.7	1.93	85[a]	11.8	2.15	100[a]	102.4	m	65[a]
Cycloxydim*	1	64.1	6.75	100[a]	5.3	1.83	100[a]	14.8	2.30	100[a]	185.9	m	100[b]
	2	54.3	6.00	100[a]	10.6	2.28	100[a]	15.7	2.73	100[a]	183.7	m	100[b]
Pyridate	1	31.9	4.33	100[a]	3.1	1.14	80[a]	-8.4	1.58	100[a]	146.8	m	100[b]
	2	32.2	4.40	100[a]	2.2	0.78	90[a]	5.6	1.15	100[a]	144.5	m	100[b]
Tribenuron methyl	1	40.1	5.28	100[a]	5.9	2.00	100[a]	17.8	2.23	100[a]	115.1	m	100[b]
	2	25.0	5.25	100[a]	4.9	2.25	100[a]	15.6	2.75	100[a]	137.7	m	100[b]
P control *vs* herbicide (df 4,26)		0.014	<0.001	-	0.070	<0.001	-	0.029	0.094	-	<0.001	m	-
SED control *vs* treatment (df 26)		10.01	0.544	-	6.50	0.401	-	5.14	0.517	-	16.90	m	-
LSD control *vs* treatment (df 26)		20.58	1.117	-	13.36	0.825	-	10.57	1.063	-	34.74	m	-

Species		Sweet Chestnut *Castanea sativa* (Mill.)			Sycamore *Acer pseudoplatanus* (L.)			Willow *Salix* sp.			Corsican Pine *Pinus nigra* var. *maritima* (Ait.) Melville.		
Herbicide	Rate	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.
Control	0	11.1	1.71	95[a]	48.3	3.61	96[a]	140.6	m	99[a]	5.9	1.47	100[a]
Amidosulfuron	1	15.8	2.83	100[a]	43.0	5.18	100[a]	126.4	m	95[a]	6.7	2.53	100[a]
	2	17.7	2.93	95[a]	37.0	4.33	100[a]	115.4	m	100[a]	3.2	2.18	100[a]
Cyanazine	1	5.7	1.45	100[a]	15.6	2.98	90[a]	111.4	m	95[a]	4.4	1.80	100[a]
	2	8.0	2.10	100[a]	23.7	3.53	100[a]	71.0	m	95[a]	3.2	1.35	100[a]
Cycloxydim*	1	13.2	2.55	100[a]	35.1	3.10	100[a]	181.9	m	100[a]	6.3	2.30	100[a]
	2	19.0	2.80	95[a]	32.8	3.23	100[a]	166.9	m	100[a]	5.2	2.23	100[a]
Pyridate	1	3.9	1.43	100[a]	5.8	2.19	95[a]	105.2	m	95[a]	2.9	1.21	95[a]
	2	8.4	1.83	95[a]	10.0	2.33	90[a]	98.1	m	95[a]	4.7	1.15	95[a]
Tribenuron methyl	1	17.8	2.55	100[a]	26.1	3.33	100[a]	122.7	m	95[a]	4.9	2.18	100[a]
	2	16.1	2.75	100[a]	30.1	3.20	100[a]	133.5	m	100[a]	6.1	2.25	100[a]
P control *vs* herbicide (df 4,26)		0.096	0.032	-	<0.001	<0.001	-	<0.001	m	-	0.100	<0.001	-
SED control *vs* treatment (df 26)		7.38	0.477	-	6.88	0.455	-	13.51	m	-	1.16	0.320	-
LSD control *vs* treatment (df 26)		15.17	0.982	-	14.15	0.935	-	27.82	m	-	2.38	0.658	-

Species		Douglas Fir *Pseudotsuga menziesii* (Mirbel.) Franco			Japanese Larch *Larix kaempferi* (Lam.) Carr.			Lodgepole Pine *Pinus contorta* (Dougl. ex Loud.)			Noble fir *Abies procera* (Rehd.)		
Herbicide	Rate	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.
Control	0	27.4	3.02	100[a]	37.2	3.37	70[abcd]	20.6	2.49	91[a]	2.3	1.34	90[a]
Amidosulfuron	1	28.0	3.60	100[a]	43.9	4.00	100[e]	21.9	3.20	100[a]	2.7	1.33	95[a]
	2	33.7	3.90	100[a]	39.0	4.53	95[de]	19.9	2.93	100[a]	4.1	2.03	100[a]
Cyanazine	1	23.3	3.13	100[a]	38.3	3.45	85[bcde]	21.6	2.19	95[a]	3.6	1.72	90[a]
	2	22.9	2.85	100[a]	43.3	3.41	90[cde]	17.7	2.75	100[a]	2.3	1.28	100[a]
Cycloxydim*	1	37.1	3.65	100[a]	45.1	4.60	75[abcd]	20.9	2.85	100[a]	4.0	2.19	85[a]

	2	28.4	3.63	100[a]	40.4	3.87	65[abc]	18.9	2.80	100[a]	3.7	1.84	85[a]
Pyridate	1	17.5	3.03	100[a]	35.3	4.00	70[abcd]	17.1	1.85	100[a]	2.8	0.64	95[a]
	2	18.9	2.55	100[a]	30.8	3.31	90[cde]	9.3	2.40	100[a]	3.0	1.10	100[a]
Tribenuron methyl	1	26.4	3.28	100[a]	56.3	4.66	95[de]	18.2	2.93	100[a]	3.7	0.95	85[a]
	2	27.9	3.40	100[a]	51.2	5.64	85[bcde]	17.9	2.98	100[a]	4.8	1.88	100[a]
P control *vs* herbicide (df 4,26)		0.210	0.030	-	0.180	0.210	-	0.580	0.013	-	0.994	0.078	-
SED control *vs* treatment (df 26)		6.00	0.418	-	10.50	0.932	-	4.84	0.357	-	1.29	0.425	-
LSD control *vs* treatment (df 26)		12.30	0.859	-	21.60	1.916	-	9.95	0.733	-	2.64	0.874	-

Species		Norway Spruce *Picea abies* (L.) Karst.			Scots Pine *Pinus sylvestris* (L.)			Sitka Spruce *Picea sitchensis* (Bong.) Carr.			Western Red Cedar *Thuja plicata* (Donn ex D. Don)		
Herbicide	Rate	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.	HtI	SDI	% Surv.
Control	0	10.1	2.01	100[a]	9.6	1.41	91[a]	22.4	3.03	98[a]	26.5	2.04	100[b]
Amidosulfuron	1	10.0	2.38	100[a]	11.4	1.59	95[a]	25.0	4.08	95[a]	16.7	1.78	100[ab]
	2	10.2	2.33	100[a]	9.8	1.09	90[a]	21.3	3.40	100[a]	19.1	3.34	85[a]
Cyanazine	1	7.7	1.40	100[a]	9.4	1.25	95[a]	**11.7**	2.48	100[a]	27.5	2.58	100[ab]
	2	8.6	2.24	95[a]	10.9	1.10	100[a]	18.3	2.98	100[a]	22.0	3.23	100[ab]
Cycloxydim*	1	7.9	2.48	90[a]	10.2	1.68	100[a]	23.5	3.48	100[a]	24.1	3.21	95[ab]
	2	11.0	2.80	95[a]	9.2	1.38	95[a]	19.7	3.14	95[a]	21.9	2.83	100[ab]
Pyridate	1	7.7	1.68	100[a]	10.7	1.10	100[a]	7.7	2.03	100[a]	16.2	3.12	95[ab]
	2	7.6	1.06	95[a]	12.0	0.75	100[a]	6.5	2.10	95[a]	19.2	2.20	95[ab]
Tribenuron methyl	1	8.3	2.35	100[a]	10.4	1.35	85[a]	21.3	3.75	100[a]	19.5	4.37	95[ab]
	2	9.7	2.25	100[a]	9.9	1.36	90[a]	23.6	3.18	100[a]	27.6	3.43	100[ab]
P control *vs* herbicide (df 4,26)		0.553	0.003	-	0.450	0.327	-	0.183	0.002	-	0.882	0.563	-
SED control *vs* treatment (df 26)		1.65	0.358	-	3.05	0.416	-	4.01	0.392	-	7.08	0.928	-
LSD control *vs* treatment (df 26)		3.39	0.736	-	6.27	0.855	-	8.25	0.805	-	14.60	1.907	-

m = data not recorded (planted as cuttings). * Plus Actipron adjuvant oil (97% highly refined mineral oil; Joseph Batsons Ltd) at 0.8% of final spray volume. HtI and SDI values that are significantly lower than the control using the LSD test at $P \leq 0.05$ are shown in bold. Within each species, survival results sharing the same letter are not significantly different.

Table 3. *Indicative potential tolerance of trees to amidosulfuron, cyanazine, cycloxydim, pyridate and tribenuron methyl*

Species	Amidosulfuron		Cyanazine		Cycloxydim		Pyridate		Tribenuron methyl	
kg a.i. ha^{-1}	0.03	0.06	2	4	0.45	0.9	0.9	1.8	0.015	0.03
Alder	MS*	MS*	MS*	MS*	MR	MR	MS*	MS*	MS*	MS*
Ash	MR	MS	MS*	MS (S)*	MS	MR	S*	MS*	MS*	MS*
Beech	R	S	MS*	MS*	MS	MR	MS*	MS	MR	MS
Birch	MR	MS	MS*	S*	MR	S	MS*	MS*	MR	MR
Cherry	MS	MS	MS*	MS*	MR	MR	MS	MS	MS	MS*
Norway maple	MS	S*	MS*	S*	MS (S)*	S	S*	MS*	MS*	S*
Oak	R	R	MS	MS	R	R	MS*	MS	R	MR
Poplar	MS*	MS*	MR*	S*	R	R	MR*	MR*	MS*	MS*
Sweet chestnut	S	R	MS	MS	R	R	MS	MR (MS)	R	R
Sycamore	MS*	MR	MS*	MS*	MS*	MS*	MS*	MS*	MS*	MS*
Willow	MR	MR	MR*	MS*	R	R	MS*	MS*	MR	MR
Corsican pine	R	MS	MS	MS	R	MR	MS	MR	MR	R
Douglas fir	MR	MR	MR	MR (MS)	R	R	MS	MS	R	R
Japanese larch	MR	MR	S	S	S	S	R (S)	S	R	S
Lodgepole pine	R	R	MR	MR	MR	R	MS	MS	MR	MR
Noble fir	MR (S)	MS	MR	MS	MS	S	MS	MS	MS	MS
Norway spruce	MR	R	MS	MR	MS	MS	MR (MS)	MS*	MR	MS
Scots pine	R	MR	MR	MR	MS	S	S	MS	MS	R
Sitka spruce	MR	MS*	MS*	MR	R	MS	MS*	MS*	MR	MS*
Western red cedar	S	S*	R	MR	R	MR	MS	S*	S*	S*

Based on the lowest (poorest) survival, height and stem diameter results compared to the control, from either application date data for year one only. Values in brackets indicate worse susceptibility for the year 2 data. Ratings are indicative and not to be taken as likely field susceptibility without further confirming evidence. Tolerance scores have been devised using the following scale:-

R = Resistant:- <5% reduction in survival, and <10% reduction in growth increment (HtI or SDI), compared to the untreated control.

MR = Moderately Resistant:- <10% reduction in survival, and 11-25% reduction in growth increment (HtI or SDI), compared to the untreated control.

MS = Moderately Susceptible:- <10% reduction in survival, and >26% reduction in growth increment (HtI or SDI), compared to the untreated control.

S = Susceptible:- ≥10% reduction in survival, compared to the untreated control.

* = significantly different from the control treatment for HtI and/or SDI and/or % survival in either the June or July application using LSD test at $P \leq 0.05$.

these herbicides at the lower dose rates, echoing the results of Lawrie & Clay (1994*a,b*) and Dixon *et al*. (2006). Many actively growing broadleaved species, such as alder, poplar, Norway maple (and for tribenuron methyl only, ash and sycamore) were severely damaged by these herbicides, as was also found by Clay *et al*. (1992), Clay & Dixon (1993), Britt *et al*. (2000), Fraser *et al*. (2001) and Dixon *et al*. (2006). However, birch, willow, oak, beech, cherry and sweet chestnut did not appear to be severely affected by the lower dose rates of sulfonyl urea herbicides used in this study.

Previous work (Dixon & Clay, 1996; Dixon *et al*., 2006) indicating that some actively growing broadleaved species were also reasonably tolerant to overspraying with pyridate is only partially supported. Most broadleaved species were damaged, although some (Norway maple, oak and poplar, damaged by the June application, and ash, Norway maple and sycamore, damaged by the July application) did apparently recover by the end of the second growing season. Similar results were seen for cyanazine in this study; most broadleaved species were damaged by both June and July applications but many recovered by the end of year 2. Conifers were more resistant.

Based on our results, Table 3 summarises the indicative potential tolerance of the herbicides tested, adopting a conservative approach by taking into account large but non-significant reduction in survival. This would indicate that as possible partial alternatives to the use of triazines for particular weed problems, cycloxydim appears to be generally safe on most actively growing tree species. This has been confirmed by operational experience. The two sulfonyl urea herbicides, amidosulfuron and tribenuron methyl may have potential for use over actively growing conifers, but only a limited number of broadleaved species showed any degree of tolerance to applications of these herbicides. Although pyridate may have potential as a dormant season spray, in our work it caused damage to the majority of actively growing species. However, given the variable nature of some of these results, more work is required to confirm the effects of amidosulfuron, tribenuron methyl and pyridate on actively growing and dormant tree species before any firm conclusions can be drawn on their safety as potential alternatives to the use of triazines.

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